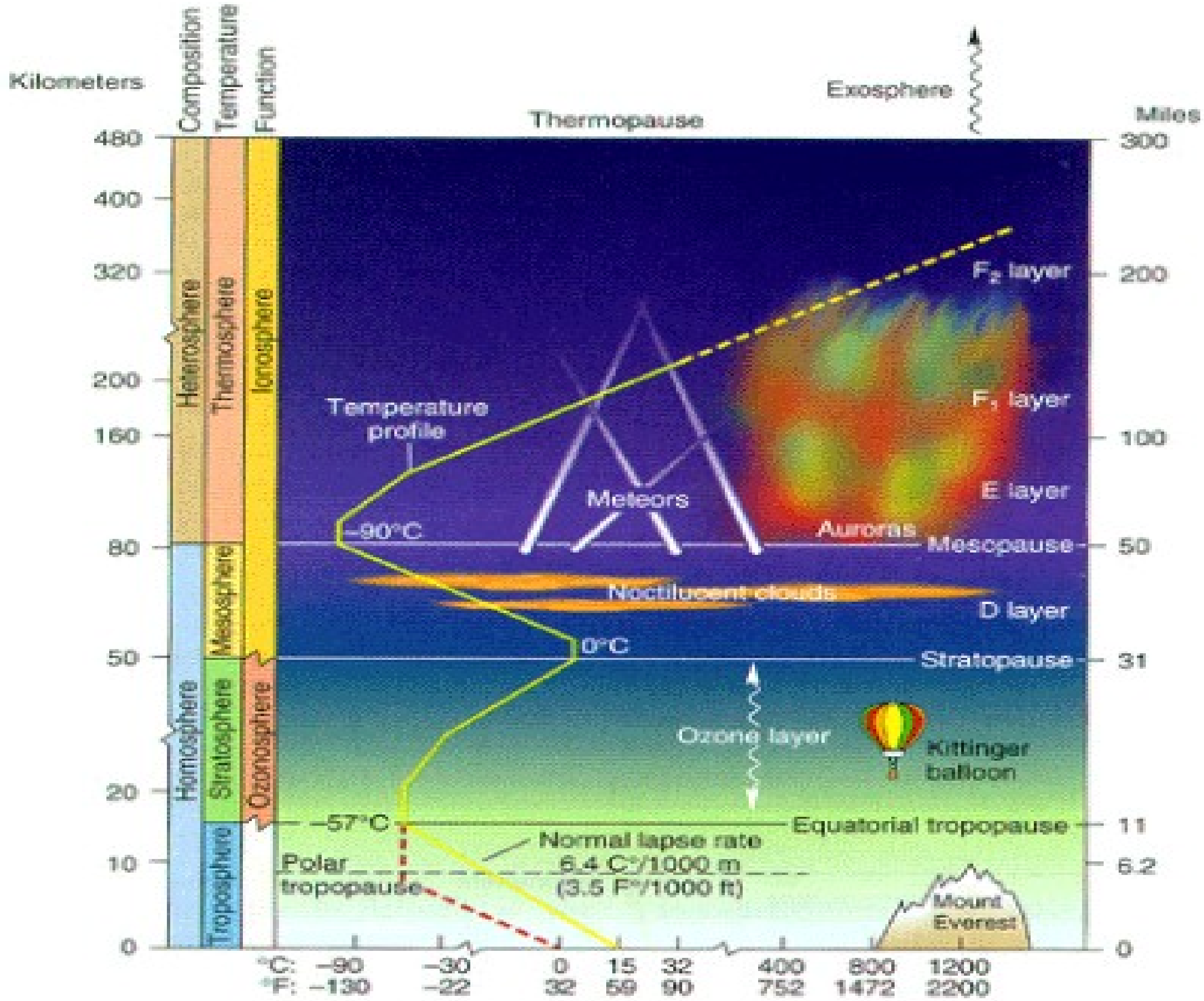
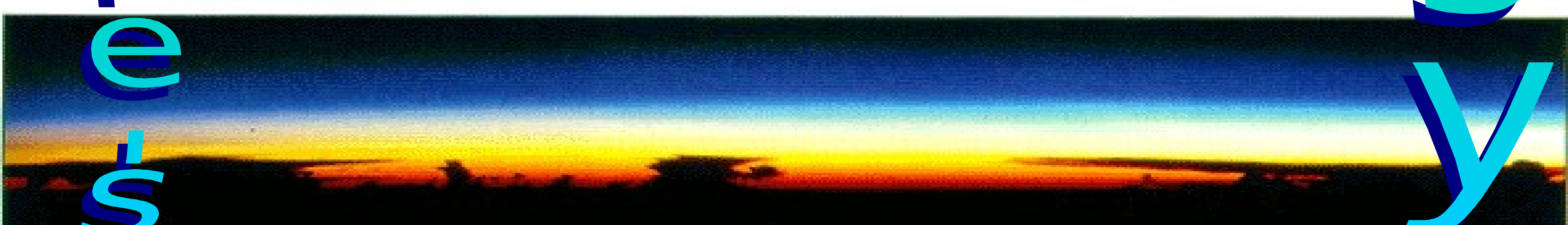
Atmosphere's Energy





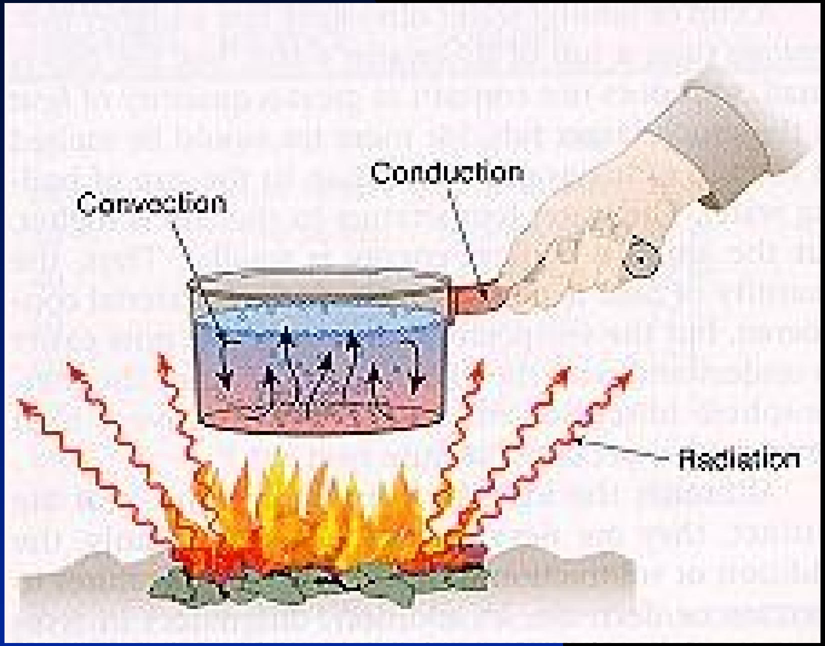
source: Christopherson (2000) Geosystems

The Atmosphere's Energy

Energy Budgets and Heat Engines

The law of the conservation of energy requires that we account for all of the energy received by the Earth. Energy is conserved. Essentially all of the energy the Earth receives comes directly from the sun (99.98%). Kinetic energy describes the differences in temperature within the atmosphere (energy of the air in motion or wind energy). Think of a automobile engine for example. The engine turns the pistons by differences in kinetic energy (temperature differences between the inside and outside of the cylinders). The kinetic energy is transmitted to the pistons which, in turn, moves the crank, which, in turn, moves the transmission which, in turn, moves the axle ……. Each of these motions is

The atmosphere operates very much like a heat engine in an automobile. In the atmosphere, however, the energy provided by the sun is distributed around the Earth by winds, precipitation, and evaporation processes. Heat energy is transmitted through processes of **Conduction, Convection, and Radiation**.



The 3 mechanisms of heat transfer: CONDUCTION, CONVECTION, RADIATION

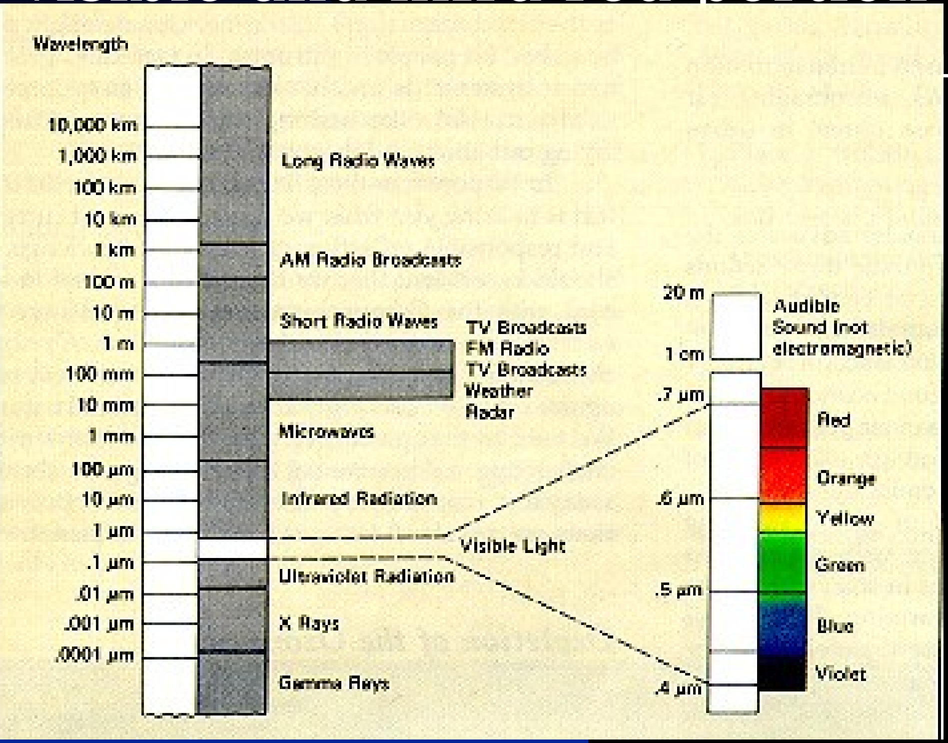
Turbulence and friction are constantly bleeding off some of this energy so that the transfer of energy is not simple.

Solar Energy

Our sun generates approximately 5.6 X 10 27 calories every minute or 3.9 X 1023 kilowatts of power). However, the Earth only intercepts less than one part in two billion of this total. or about 2 cal/cm2/min (1370 watt/m2). This known as the **Solar Constant** **(although we do not know exactly how constant this value is).**

According to Bethe' s theory, the energy radiated from the sun is created through a complex thermonuclear reaction that converts protons (hydrogen nuclei) to alpha particles (helium nuclei). In the process, mass is converted to energy (in accordance with Einstein's familiar relationship **E = mc2**. It is the gravitational contraction in the sun that makes these reactions take place. This means that the sun is converting mass into energy at a rate of about 4 X 106 tons per second.

It is the radiant energy emitted by the sun that is the source of Earth's climate energy. This radiant energy arrives at the Earth in a broad band of **electromagnetic spectra**. 80% of the energy receives falls within the visible and infra red portion of the spectra, with peak



e blue).

Ultraviolet, visible light, IR, and many other forms of radiation are just different wavelengths of the EM spectrum

The properties shown here of the radiation spectrum follow two important laws, the Stefan-Boltzmann law and Wien's law. The Stefan-Boltzmann law relates the total amount of energy (E) radiated by a black body (perfect

E=sigmaT^4

where sigma is the Stefan Boltzman constant and

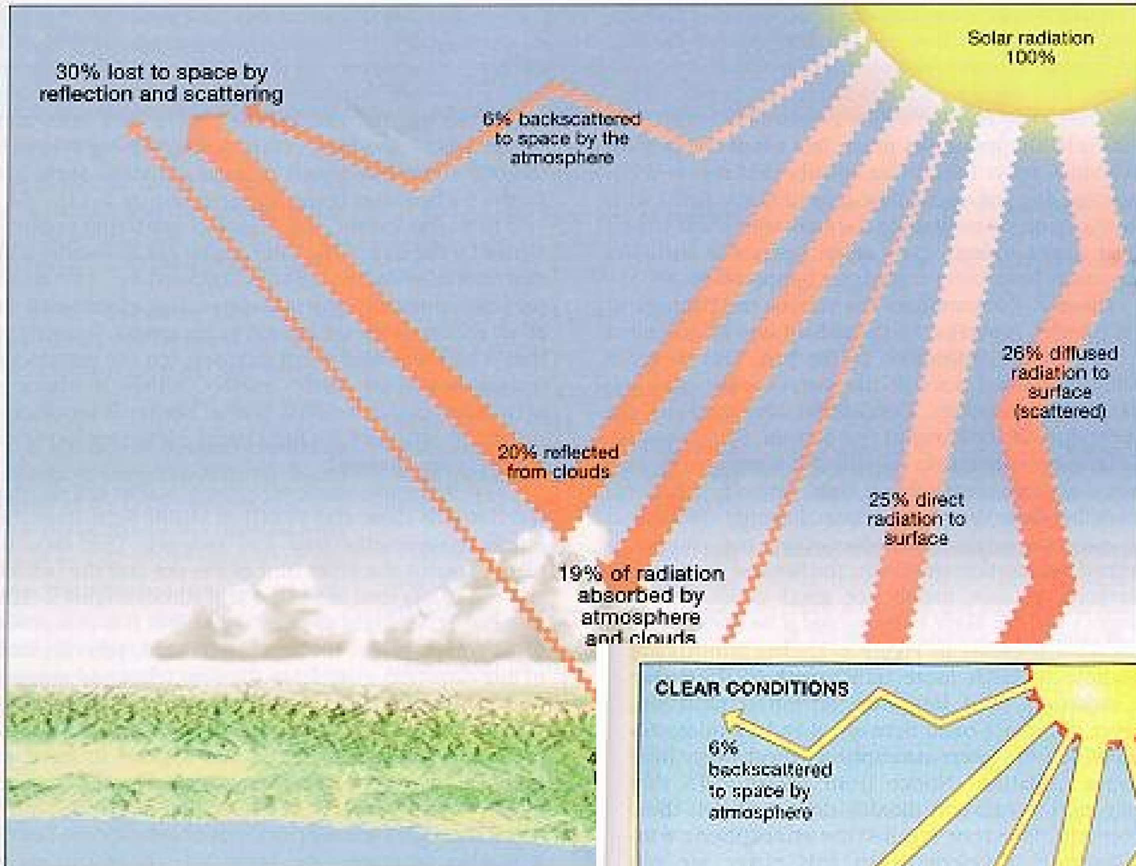
is 5.67 X 10-8 Wm^-2K^-4

The wave length at which a body emits most intensively is inversely proportional to the temperature, and is given by Wien's law

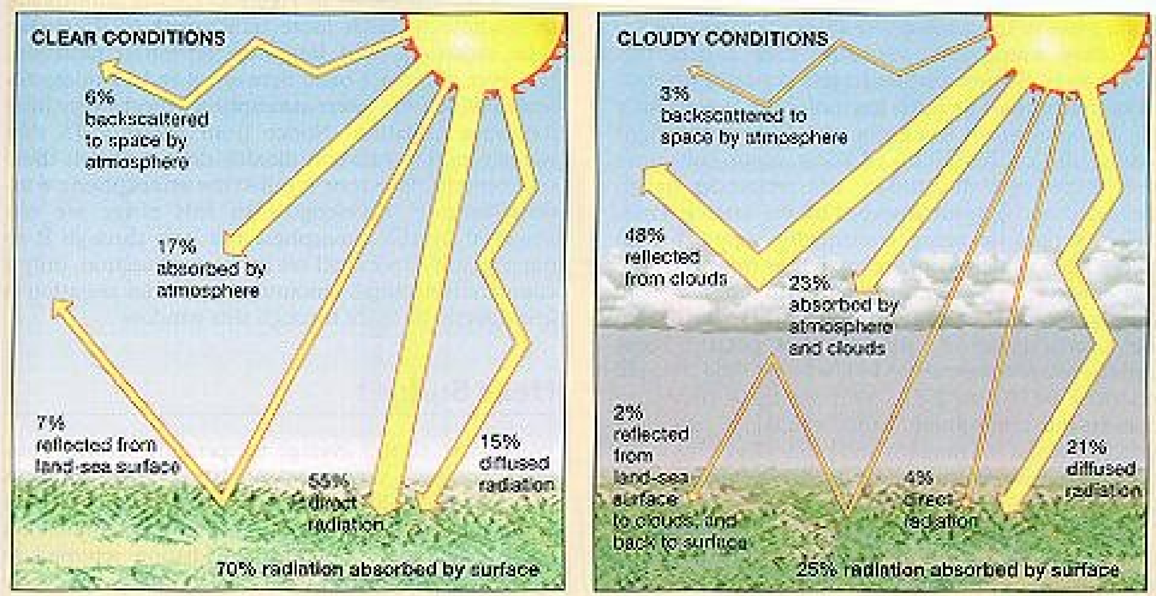
lamdamax = **C/T**

where C is 2898um K.

Wien's law explains why the sun, with at temperature of 6000k emits its maximum energy at a wavelength of about 0.5um while the Earth with a mean temperature of about 285K emits its maximum energy at about 10um. This means that hot bodies not only radiate more energy, they radiate at shorter wave lengths.



Average distribution of incoming solar radiation by perc
Earth's surface than by the atmosphere. Consequently, the air is not he
indirectly from Earth's surface.



A comparison of the average distribution of incoming solar radiation on clear and cloudy days.

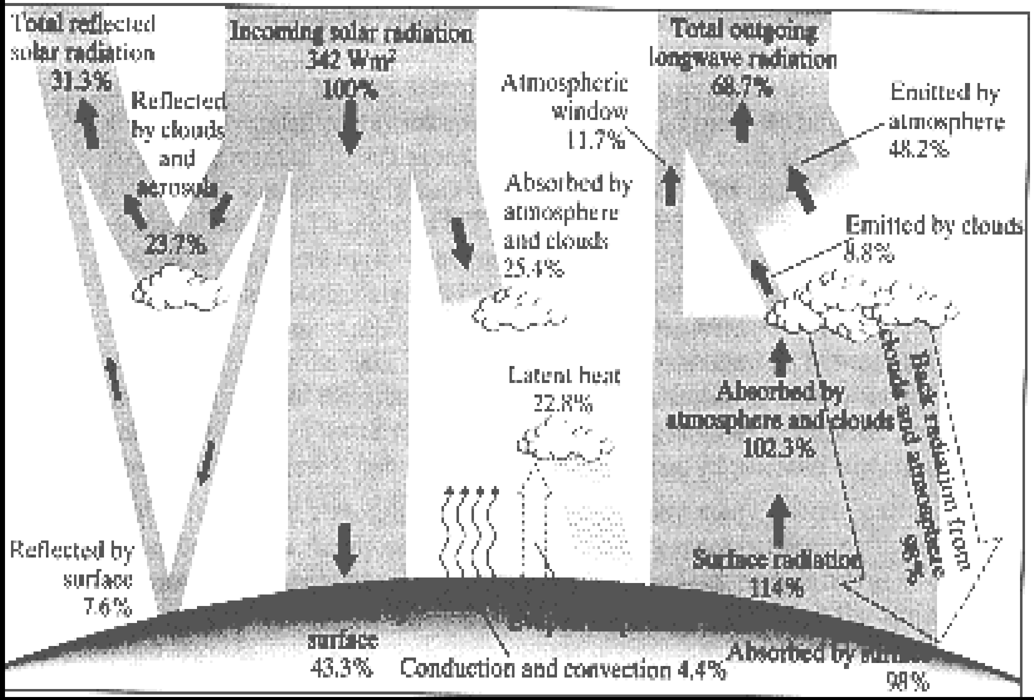
Some of the energy Earth receives from the sun in the form of electromagnetic energy pass undisturbed, some are absorbed by the atmosphere, and the rest are turned back. These effects are referred to as:

Absorption. Oxygen, ozone, water vapor, carbon dioxide and dust are the most important absorbers of short-wave length energy from the Sun and short wave radiation emitted by by the Earth.

Scattering. Small particles act as obstacles to the paths of radiant radiation.

Reflection. The radiant energy from the sun encounters clouds in the atmosphere which act to reflect back some of the energy. The reflective nature of a cloud depends primarily on its thickness but also, to some extent, on its

Of the total energy arriving from the sun (342Watts/m2), approximately 69 percent is absorbed by the Earth and the atmosphere. 31 percent is reflected by clouds and the Earth's surface.



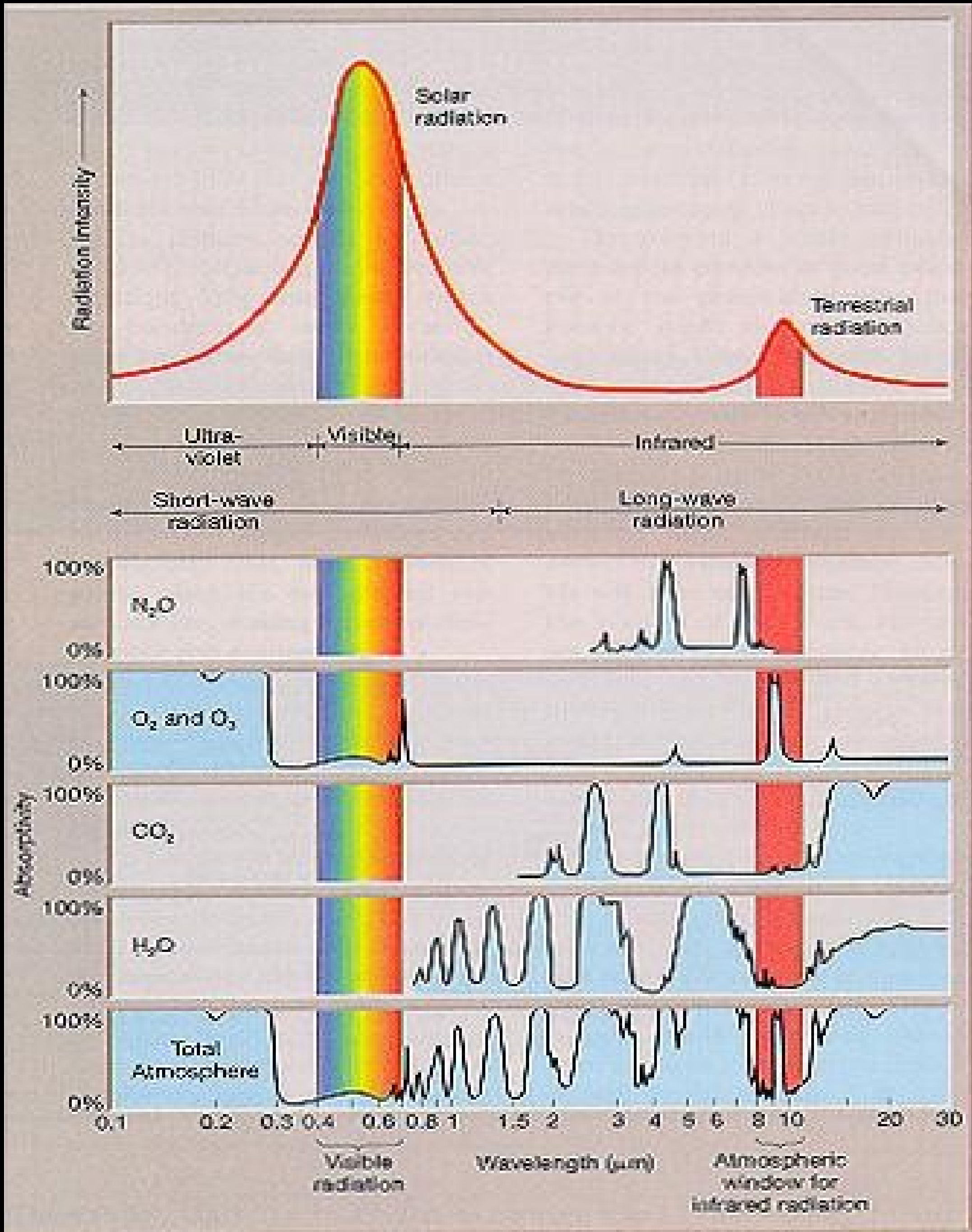
The Earth remains essentially the same temperature over long periods of time (hundreds to thousands of years). This means that there is an **Energy Balance**. In other words if the Earth absorbs 69 percent of the radiation it receives from the sun, then it must also be an equal amount re-radiated back into space. Keep in mind, however, that this balance is for the entire Earth. From region to region there are large energy imbalances. It is

Green House Effect

Also note that the Earth emits more long-wave radiation than it receives in total radiation from the Sun. This is due to the "**greenhouse effect"**, blanketing of the Earth by gases that retain (trap) energy. Three gases--

water vapor, carbon di oxide and methane

, play the most important roles in keeping the Earth warm



Seasonal and Latitudinal Variations in the Earth's Heat Energy

The energy budget of the Earth varies regionally and seasonally due to four factors:

1. The Earth is essentially a sphere

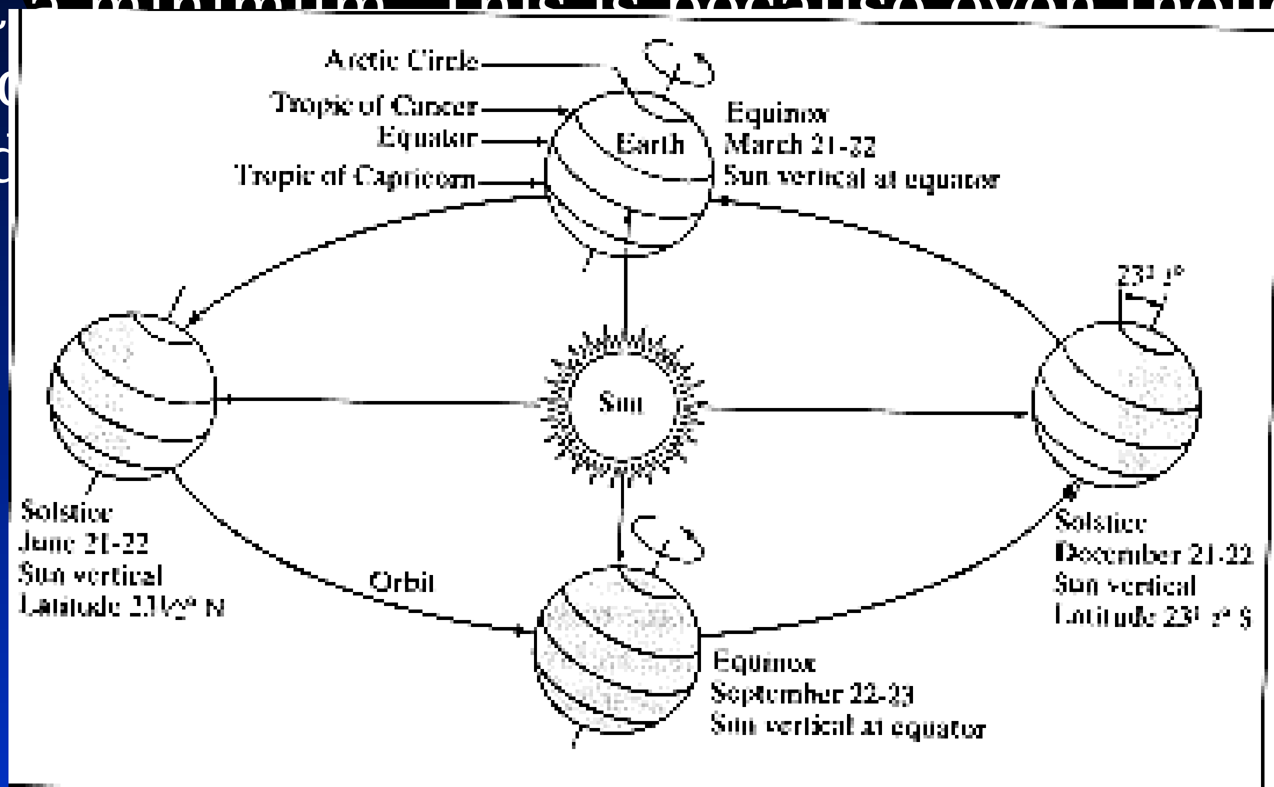
2. The Earth rotates about the sun

3. The Earth rotates about its axis

4. The Earth is so far from the sun that the sun's rays are approximately parallel.

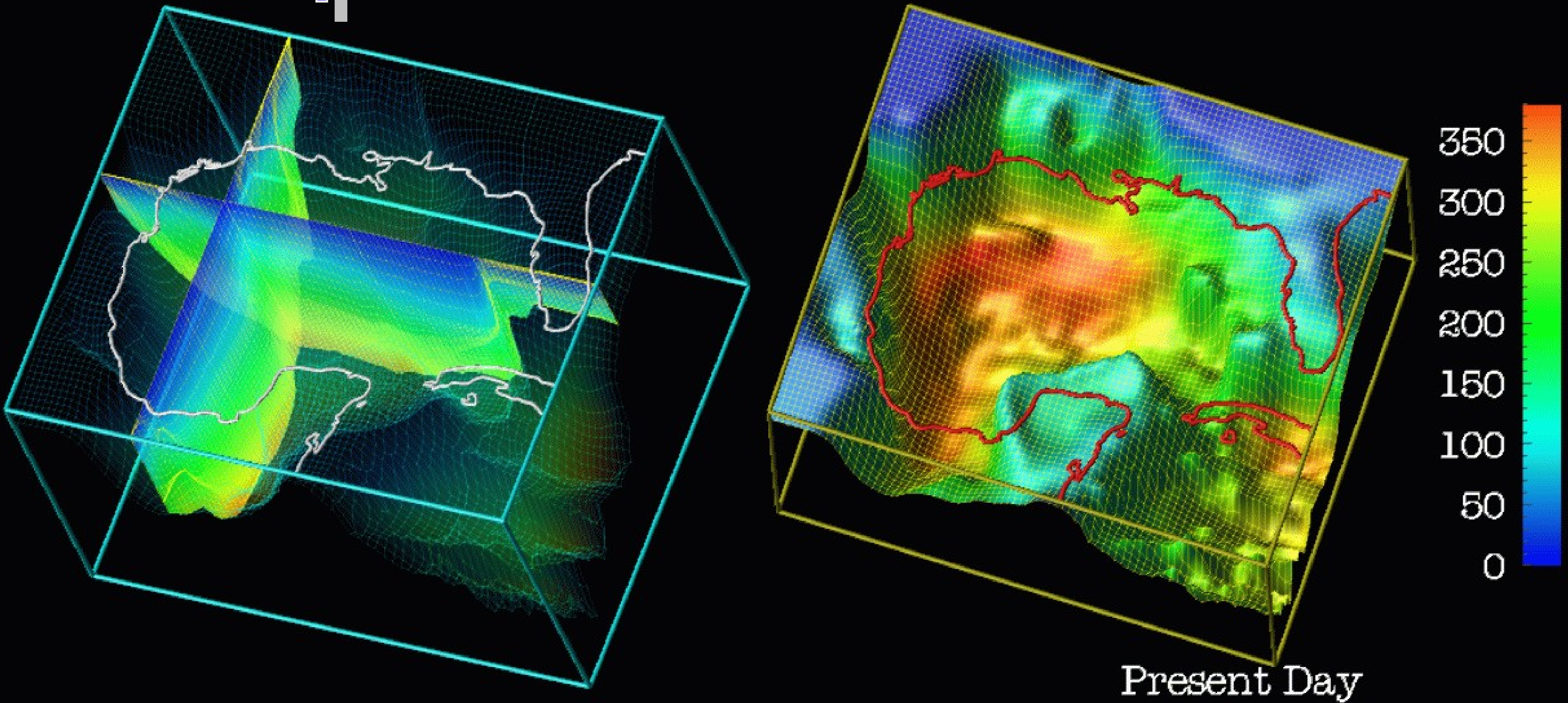
Seasons are caused by the motion of the Earth around the sun and the tilt of the Earth's axis. Without a tilting axis there would be no seasons. Hence, the degree of tilt affects the amount of seasonality each of the hemispheres experiences. The **summer solstice** marks the point during the year when the difference in the amount of solar energy received at the poles and at the equator is at a minimum. This is because even though the angle of inci

compensated

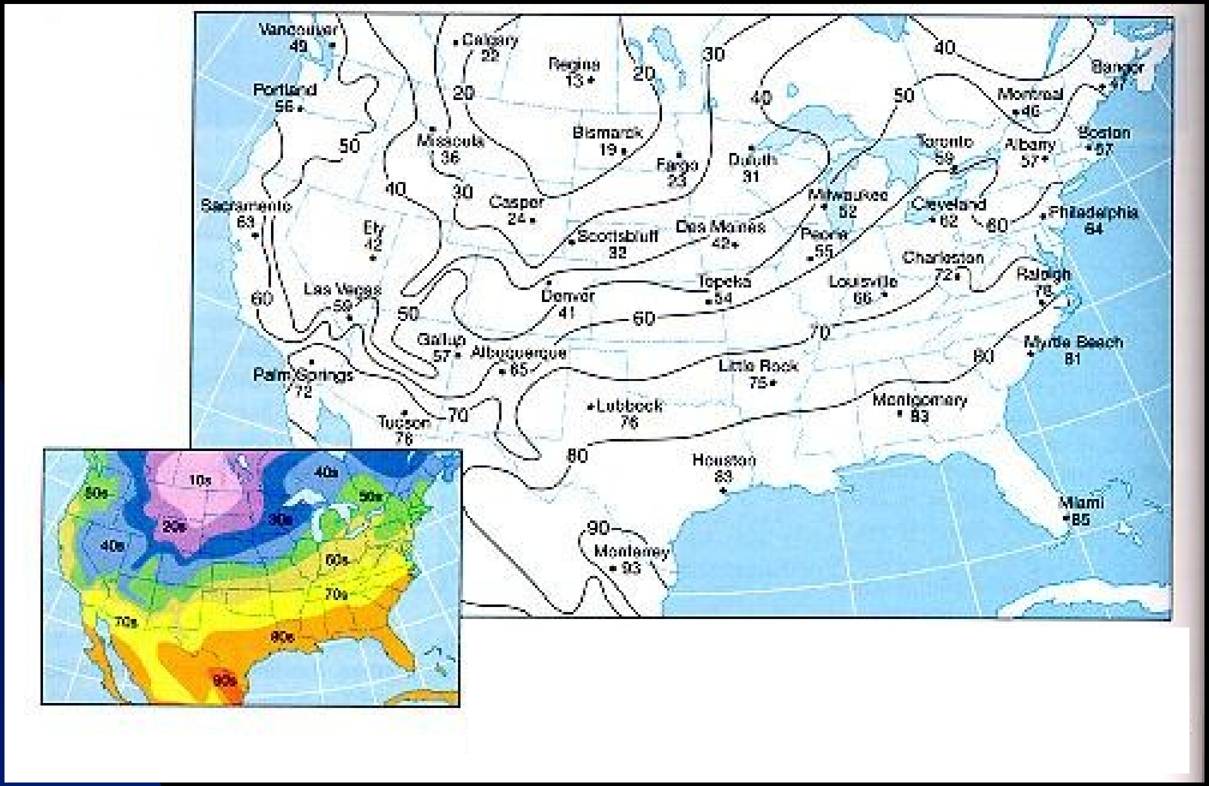


If latitudinal differences were the only variables affecting solar radiation distributions, the amount of temperature variations over the Earth would be much simpler. However, because the different thermal properties of water , land, clouds and dust, the amount of solar variation and the resulting temperature varies considerably over the planet. For example, at the same latitude, the daily temperature changes vary much less for water than for land. This accounts for the cool ocean breezes we experience here in Los Angeles in the late afternoon.

Temperature Distribution



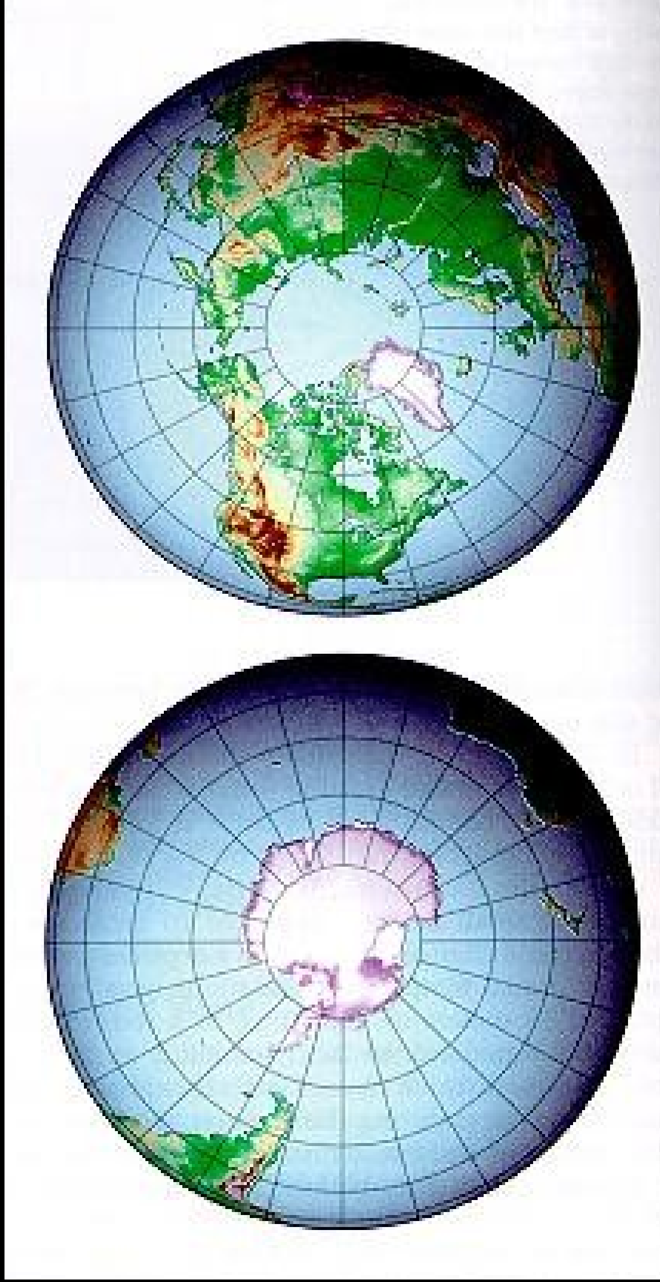
Temperature Distributions



Factors Affecting Temperature Distributions

1. **Differential heating of land and water**
2. **Ocean Currents**
3. **Altitude**
4. **Geographic position**
5. **Cloud cover and albedo**

The uneven distribution of land and water between the Northern and Southern hemisphere. Almost 81% of the Southern Hemisphere is covered by the oceans – 20% more than the Northern Hemisphere.



Note the uneven distribution of land and water in the northern and southern hemisphere.

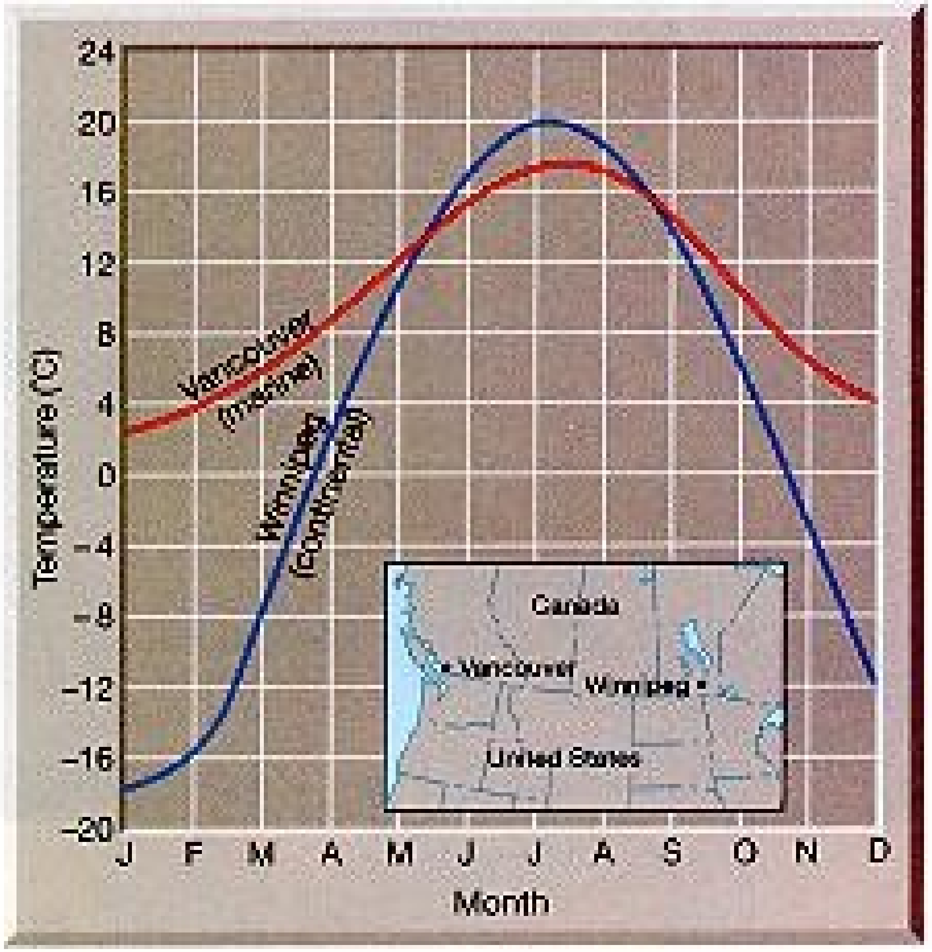


Figure 3–4 Mean monthly temperatures for Vancouver, British Columbia, and Winnipeg, Manitoba. Vancouver has a much smaller annual temperature range owing to the strong marine influence of the Pacific Ocean.

Vancouver and Winnipeg are at approximately the same latitude but have very different annual temperature patterns. Why?

The reason has to do with the influence of ocean currents and the effect water along the coast of Vancouver has on the atmosphere

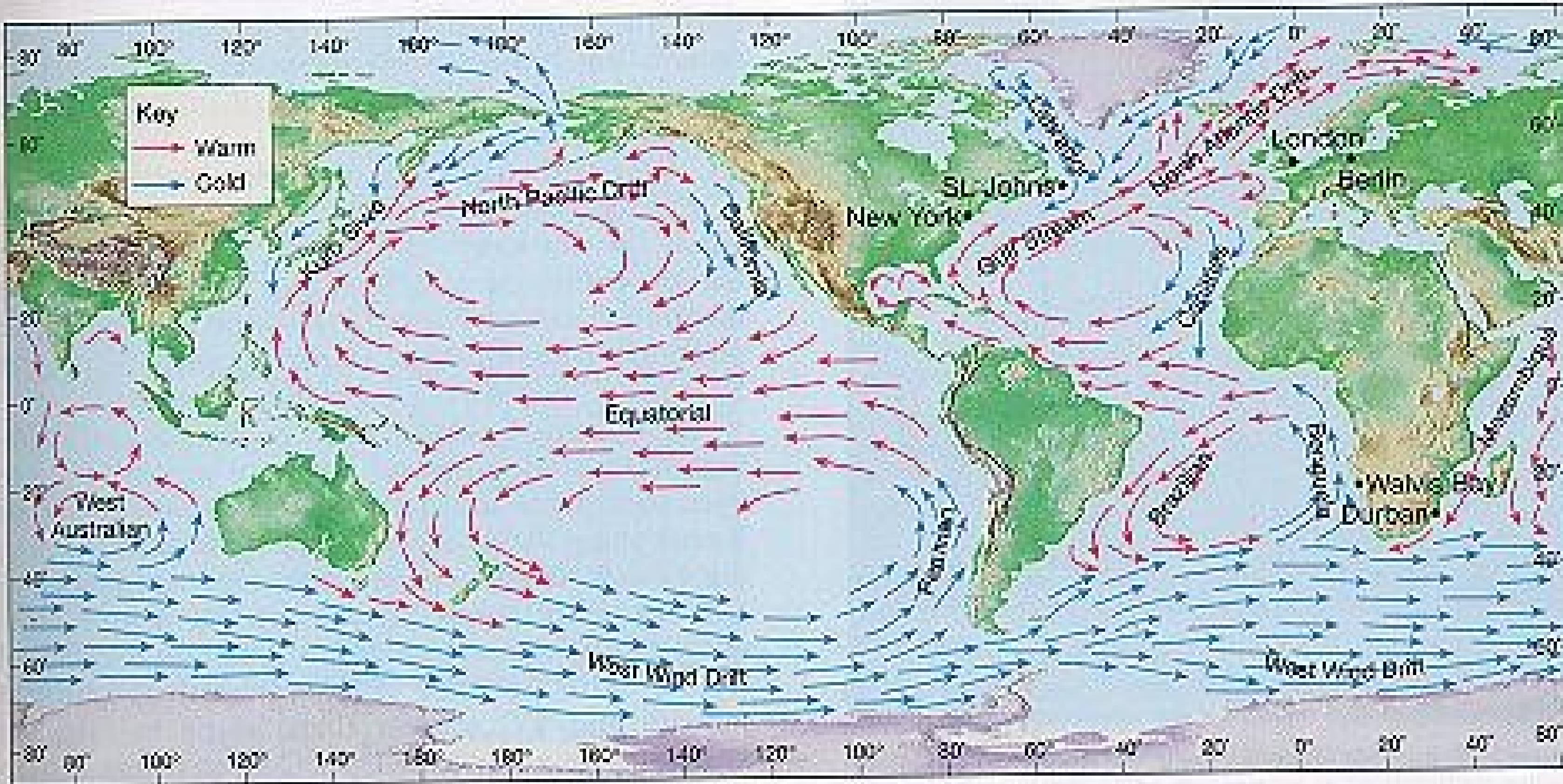


Figure 3–7 Major surface ocean currents. Poleward-moving currents are warm, and equatorward-moving currents are cold. Surface ocean currents are driven by global winds and play an important role in redistributing heat around the globe.

Look closely at the direction of current flow. Where are the warm currents and where are the cold currents?

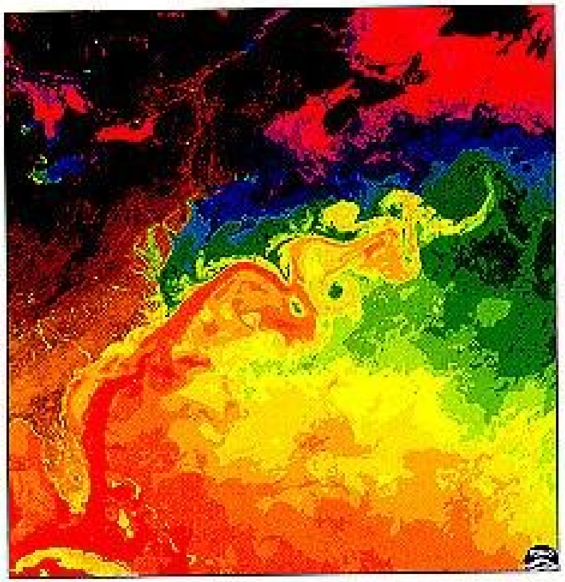


Figure 3–6 This satellite image of a portion of the North Atlantic shows the complexities of the Gulf Stream. It flows along the eastern coast of Florida and the Carolinas and northward into the North Atlantic. Reds and yellow denote warmer waters. The current transports heat from lower latitudes toward the North Pole. Meanders of the Gulf Stream pinch off to form eddies that may move about the ocean for up to 2 years before dissipating. (Courtesy of National Oceanic and Atmospheric Administration)

This is a satellite image of the Gulf Stream. The red colors depict warmer temperatures and the blue represents cooler temperatures.

Now look at the diagram and compare the temperature of Myrtle Beach with Los Angeles. Both cities are at equivalent latititudes. However, Myrtle Beach has mean temperatures that are about 10 to 15o warmer than Los Angeles.

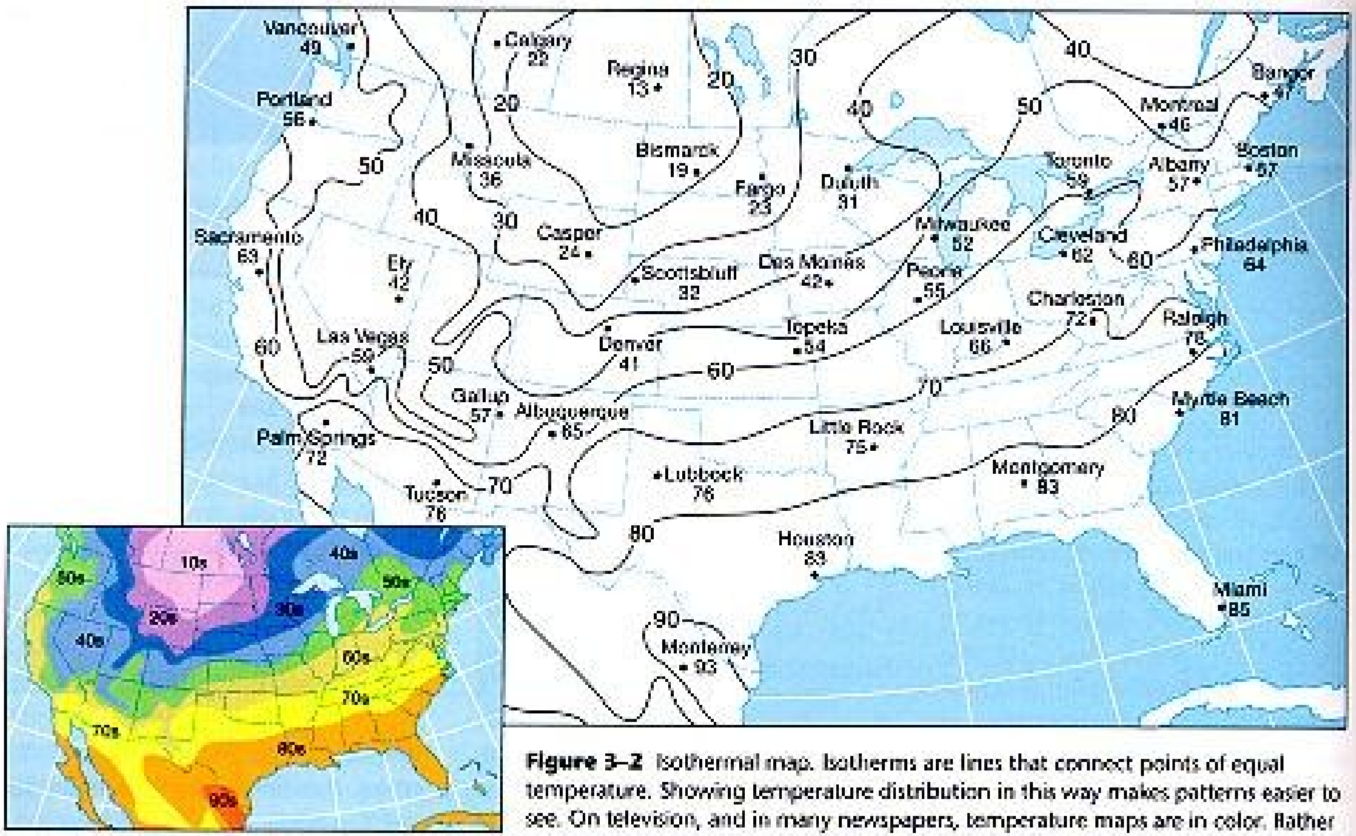


Figure 3–2 Isothermal map. Isotherms are lines that connect points of equal temperature. Showing temperature distribution in this way makes patterns easier to see. On television, and in many newspapers, temperature maps are in color. Rather than labeling isotherms, the area between isotherms is labeled. For example, the zone between the 60° and 70° isotherms is labeled "60s".

Elevation

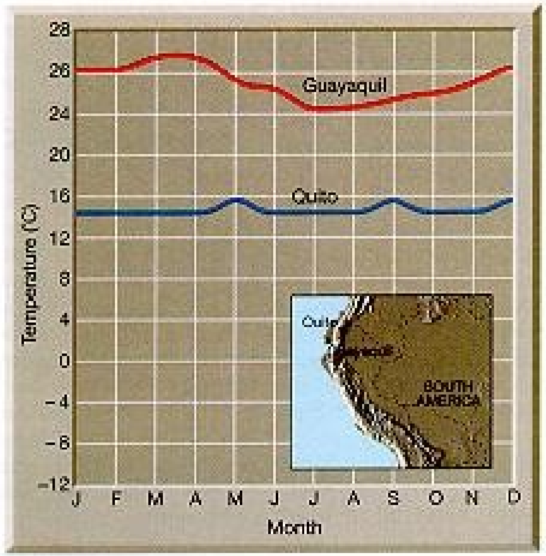


Figure 3–8 Because Quito is high in the Andes Mountains, it experiences much cooler temperatures than Guayaquil, which is near sea level.

Elevation plays a very important role in the temperature distributions on land. Compare these two Ecuadorian cities, both located very near the equator. One of the cities, Guayaquil has very little temperature variability, only about two degrees. But, the temperature is around 25o centigrade compared to Quito which has temperatures of around 13o C.

The difference between these two cities is Elevation. Guayaquil is only 12meters above sea level. Quito is at

Geographic Location

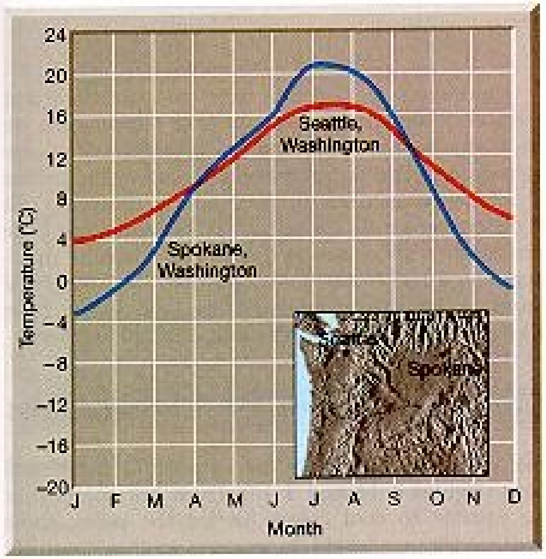


Figure 3-10 Monthly mean temperatures for Seattle and Spokane, Washington. Because the Cascade Mountains cut off Spokane from the moderating influence of the Pacific Ocean, its annual temperature range is greater than Seattle's.

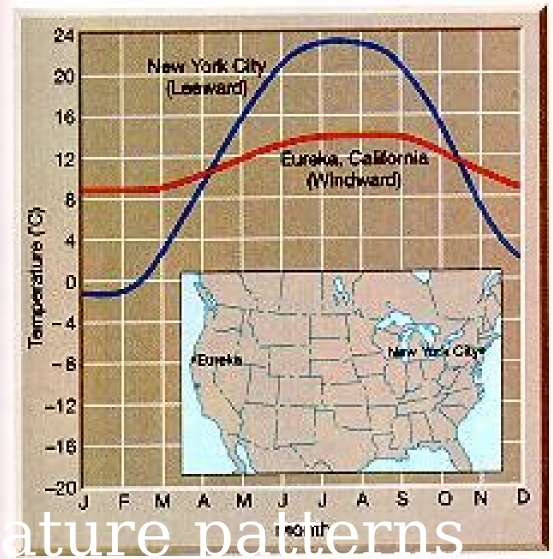


Figure 3-9 Monthly mean temperatures for Eureka, California, and New York City. Both cities are coastal and located at about the same latitude. Because Eureka is strongly influenced by prevailing winds from the ocean and New York City is not, the annual temperature range at Eureka is much smaller.

…ct the different temperature patterns seen in the cities above?

In the case of Spokane and Seattle, Seat… cooling prevailing Pacific winds. Spokane on the other hand does not because the winds are blocked by the Cascade mountain range.

Eureka and New York city are both at similar latitudes but Eureka is constantly cooled by the prevailing winds

Cloud Cover

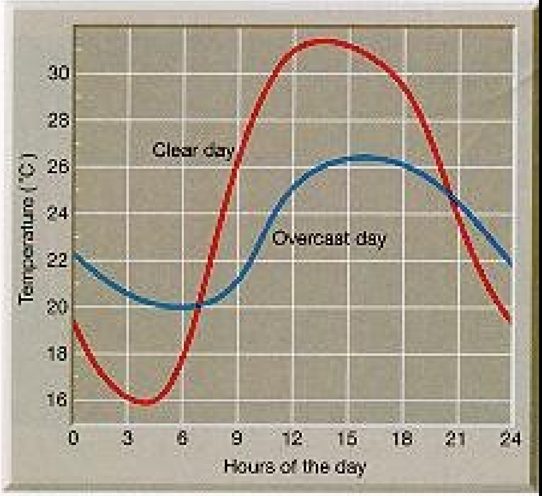


Figure 3–12 The daily cycle of temperature at Peoria, Illinois, for two July days. On the clear day, the maximum temperature was higher and the minimum temperature was lower than on the cloudy day.

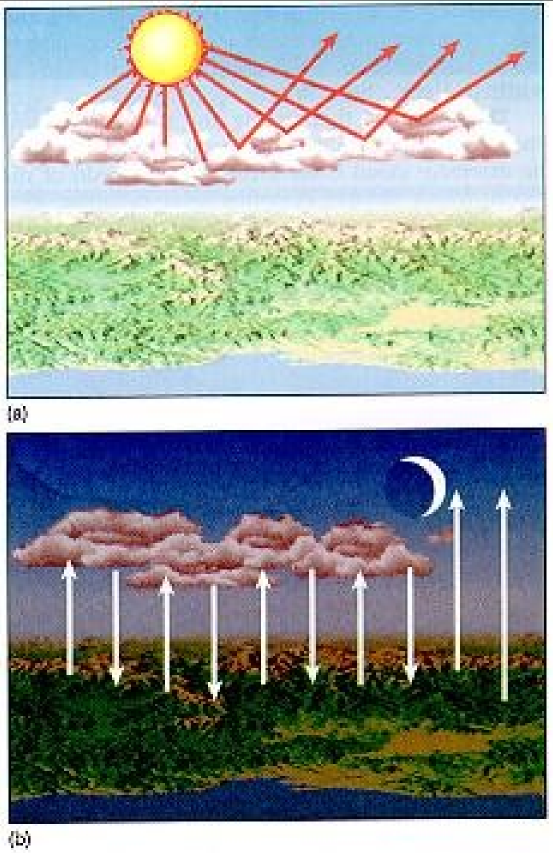


Figure 3–11 How clouds reduce the daily temperature range. (a) During daylight hours, clouds reflect solar radiation back to space. Therefore, the maximum temperature is lower than if the sky were clear. (b) At night, the minimum temperature will not fall as low because clouds retard the loss of heat.

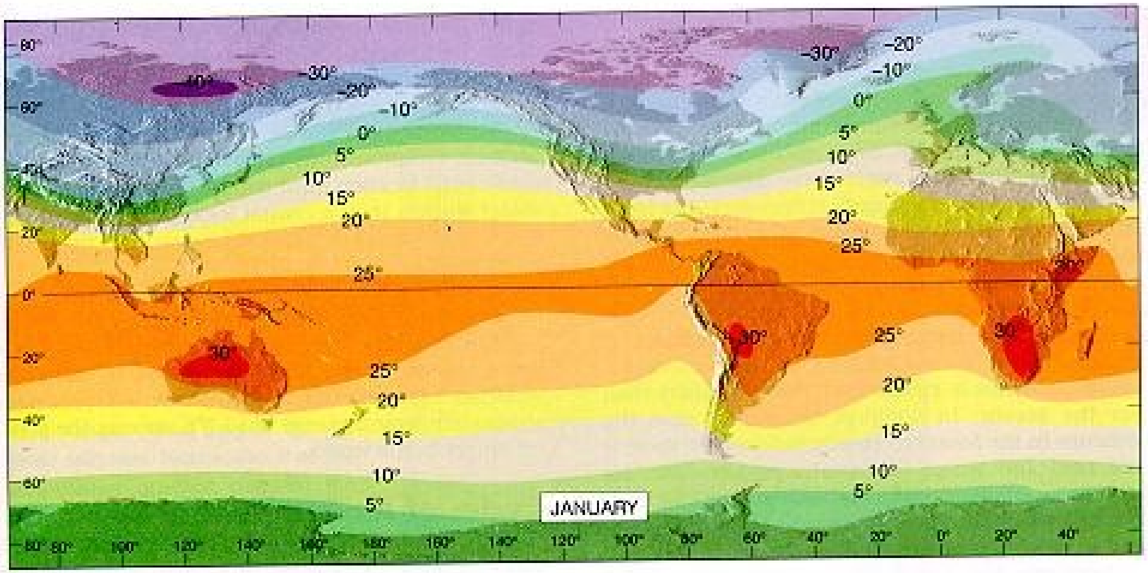


Figure 3–14 World mean sea-level temperatures in January in degrees Celsius.

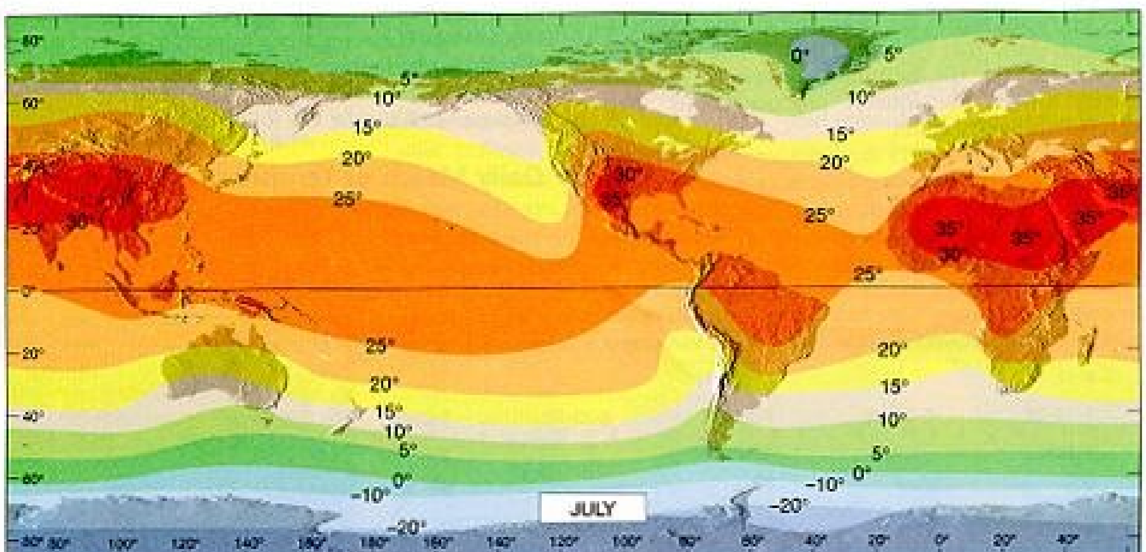


Figure 3–15 World mean sea-level temperatures in July in degrees Celsius.

Air in Motion

Air in Motion

Laws of Motion

The uneven heating the earth's surface leads to movements of air. How the heat energy is converted to kinetic energy is the topic of this section.
The first law of motion we will consider is:

1. **Newton's first law** (law of inertia). It states that for a body to change its state of motion, it must be acted upon by an unbalanced force.
2. **Newton's second law**. It states that the force required to accelerate a body of mass is given by:

$$F=ma$$

a=the acceleration (rate of change of velocity).

There are two types of forces:

1) those that exist regardless of the sate of motion of the air

examples: **Gravitation Attraction** and **Pressure**

2) those that arise only after there is motion.

examples: **Friction** and the **Coriolis Force**

Vertical Forces

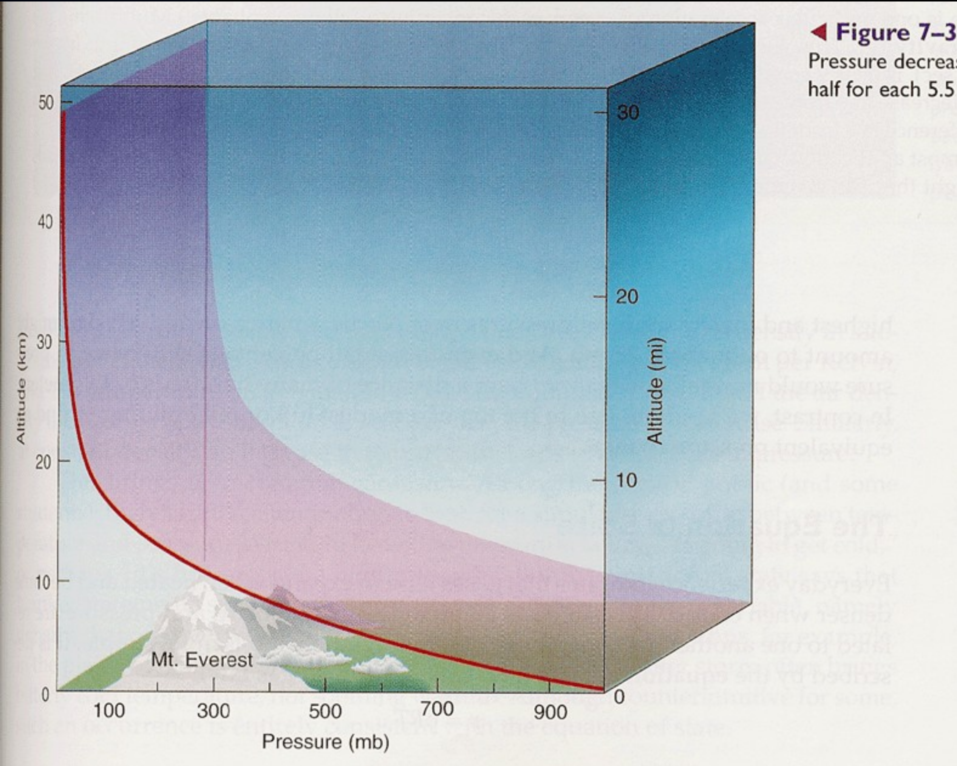
Gravitational Force is defined as: $F_g = Mg$

where Fg = gravitation force

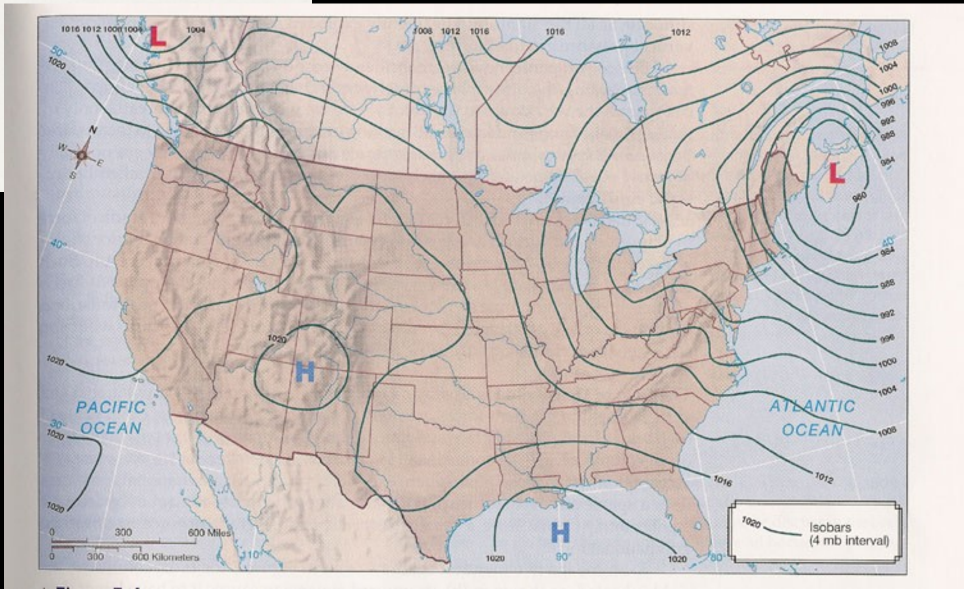
M= mass of the air

g = gravitational acceleration ($9.8 m/s^2$)

This is the downward force applied to an air mass that accounts for the change in pressure from the ground surface up through the atmosphere.



◀ **Figure 7–3**
Pressure decreases with altitude by about half for each 5.5 km (3.3 mi).



Remember Forces tend to be balanced by opposing forces

Pressure Gradient Force.

This force acts in the opposite direction and balances the gravitational force. It is defined as the magnitude of the pressure gradient force is a function of both the pressure difference between two locations and the distance between them. It must also account for the difference in air density.

It is this force that causes winds to blow. The force moves air from regions of high pressure to regions of low pressure

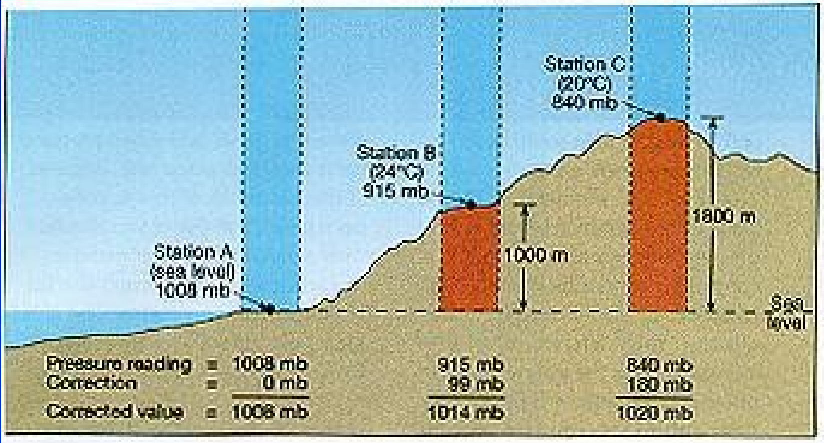
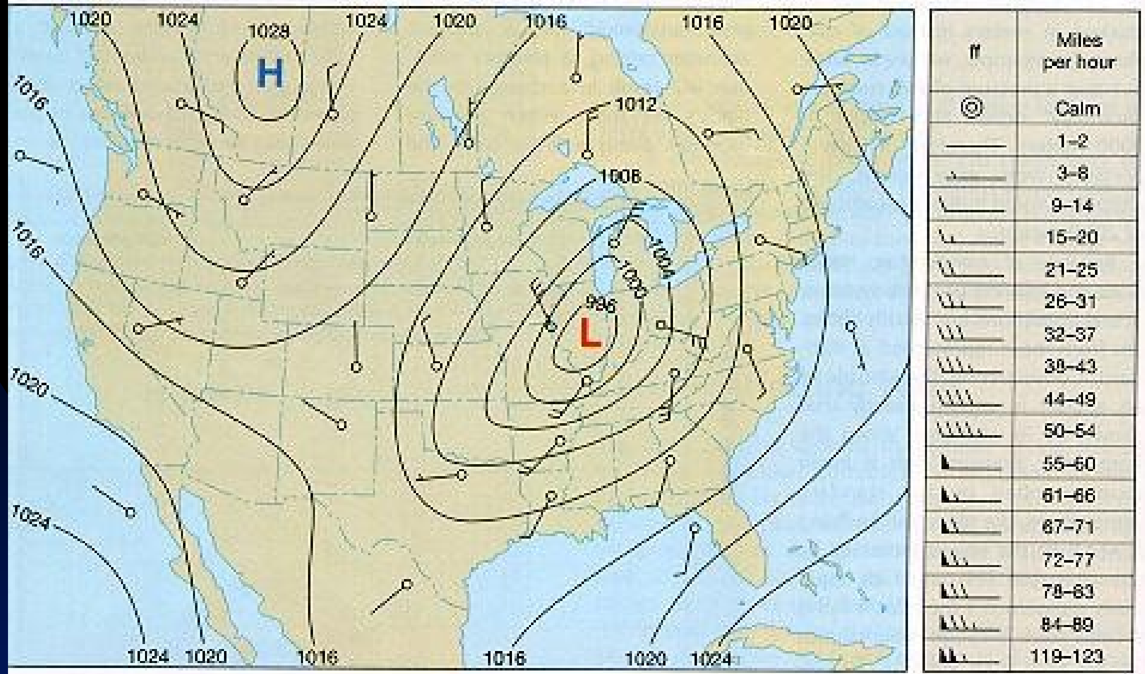


Figure 6–7 To compare atmospheric pressures, meteorologists first convert all pressure measurements to sea-level values. This is done by adding the pressure that would be exerted by an imaginary column of air (shown in red) to the station's pressure reading. (See Table C-2 in Appendix C.)



gure 6–8 Isobars are lines connecting places of equal sea-level pressure. They are used to show the distribution of essure on daily weather maps. Isobars are seldom straight, but usually form broad curves. Concentric rings of isobars dicate cells of high and low pressure. The "wind flags" indicate the expected airflow surrounding pressure cells and are otted as "flying" with the wind (that is, the wind blows toward the station circle). Notice on this map that the isobars e more closely spaced and the wind speed is faster around the low-pressure center than around the high.

The larger the pressure gradient the greater is the force applied to the air. Therefore, the greater the force, the greater is the speed of the wind. Note that the closer the contours are to one another the steeper is the pressure gradient.

Ultimately, the source of the differences in pressure between two locations is a function of differential heating

Coriolis Force "Merry-GO-Round Force"

146 CHAPTER 6 *Air Pressure and Winds*

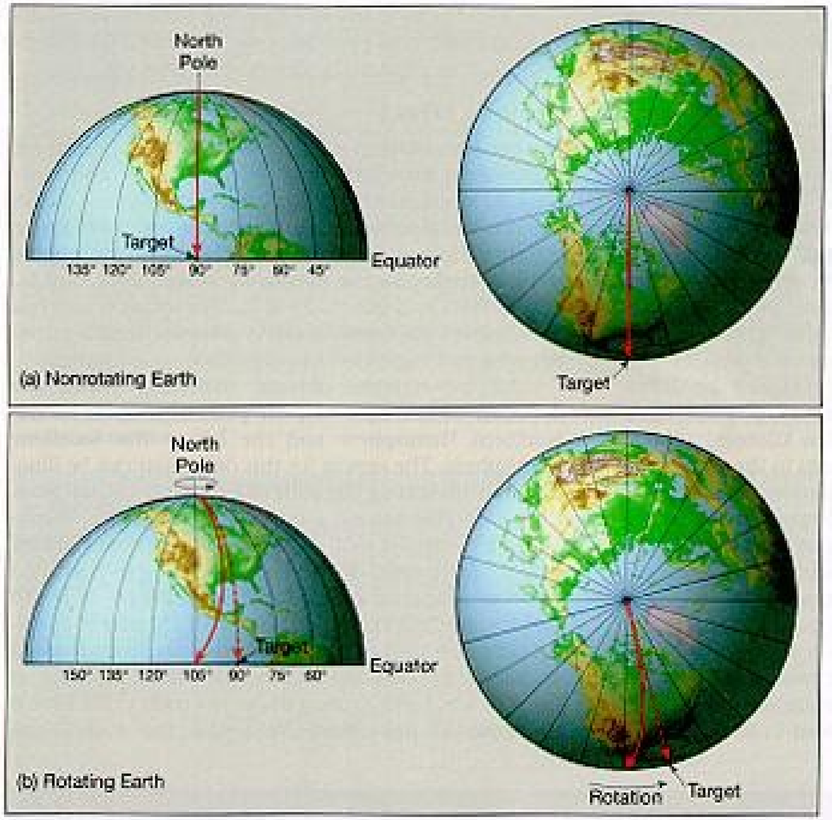
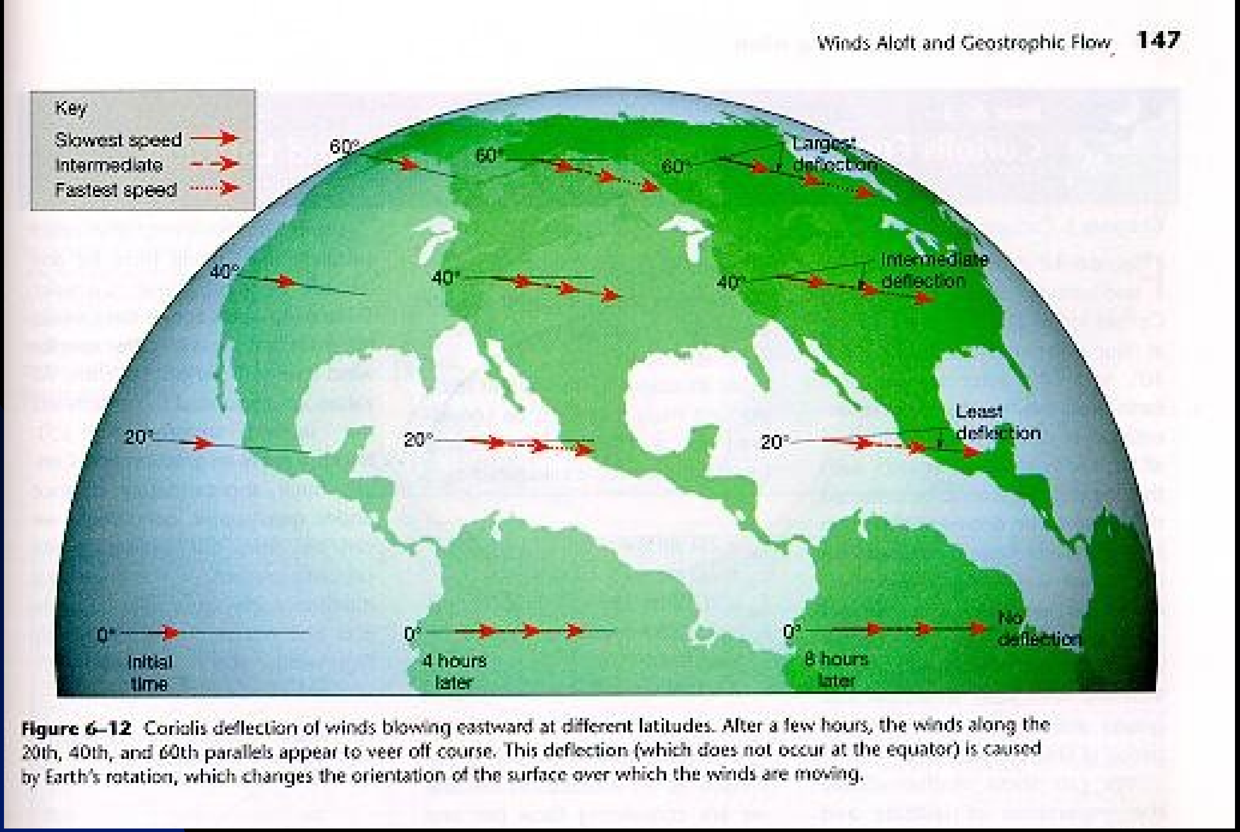


Figure 6–11 The Coriolis effect illustrated using a 1-hour flight of a rocket traveling from the North Pole to a location on the equator. (a) On a nonrotating Earth, the rocket would travel straight to its target. (b) However, Earth rotates 15° each hour. Thus, although the rocket travels in a straight line, when we plot the path of the rocket on Earth's surface, it follows a curved path that veers to the right of the target.



At the Northern Pole the apparent rotation is to the left

At the Southern Pole the apparent rotation is to the right.

This is an Apparent Force as observed on the Earth. The deflection observed by an observer on the Earth is related to the latitude, greatest at the poles and zero at the equator.

Coriolis Force is not a "real" force. It is really the effect of the Earth's rotation on a moving body.

1) The Coriolis Force always deflects winds at right angles to the direction of the airflow in the Northern Hemisphere.

2) The Coriolis Force affects only wind direction, not wind speed

3) The Coriolis Force is affected by wind speed/ the greater the wind speed--the greater the deflection.

4) is strongest near the poles, becoming weaker toward the equator and is nonexistent at the equator

Curved Paths

Gradient Winds are winds that followed the curved paths of highs and lows.

Centripetal Acceleration

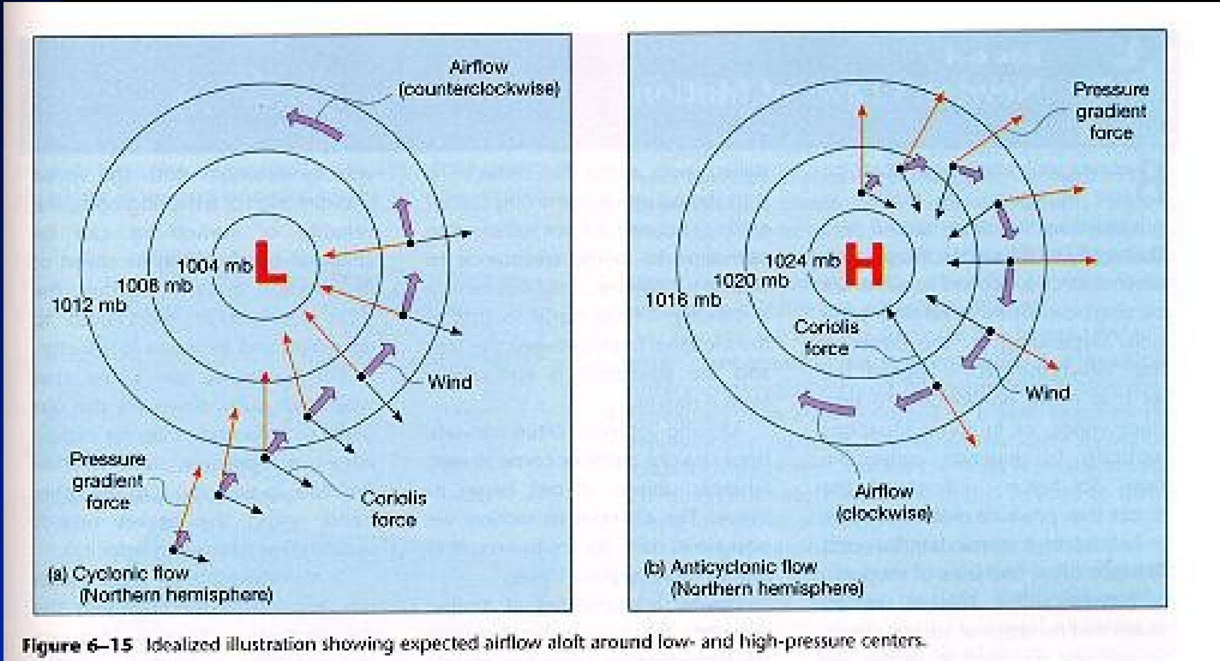


Figure 6–15 Idealized illustration showing expected airflow aloft around low- and high-pressure centers.

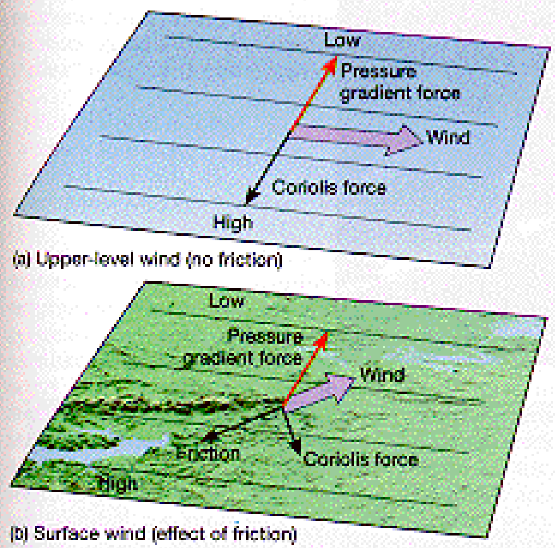


Figure 6–16 Comparison between upper-level winds and surface winds showing the effect of friction on airflow. Friction slows surface wind speed, which weakens the Coriolis force, causing the winds to cross the isobars.

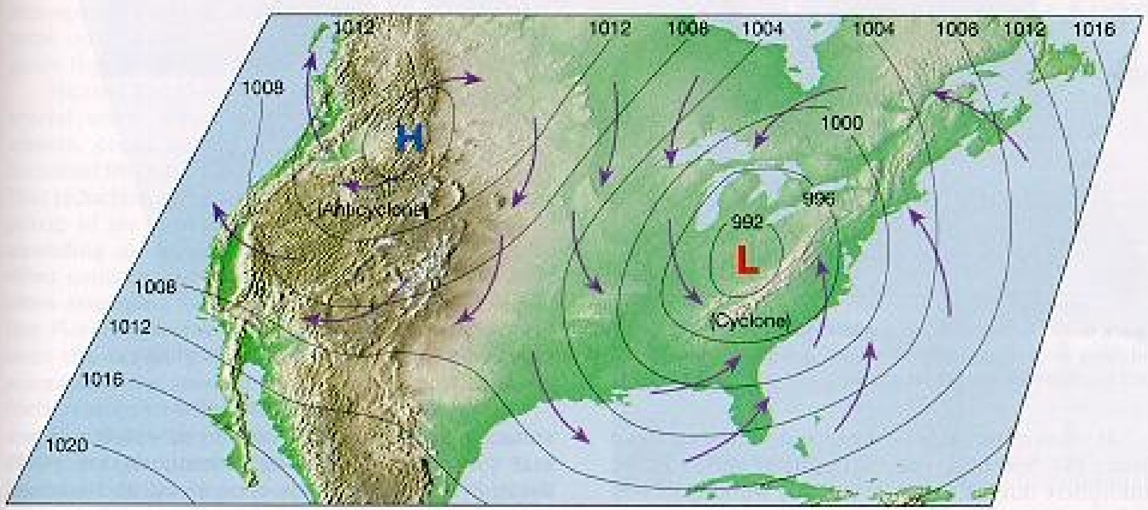


Figure 6–17 Cyclonic and anticyclonic winds in the Northern Hemisphere. Arrows show the winds blowing inward and counterclockwise around a low, and outward and clockwise around a high.

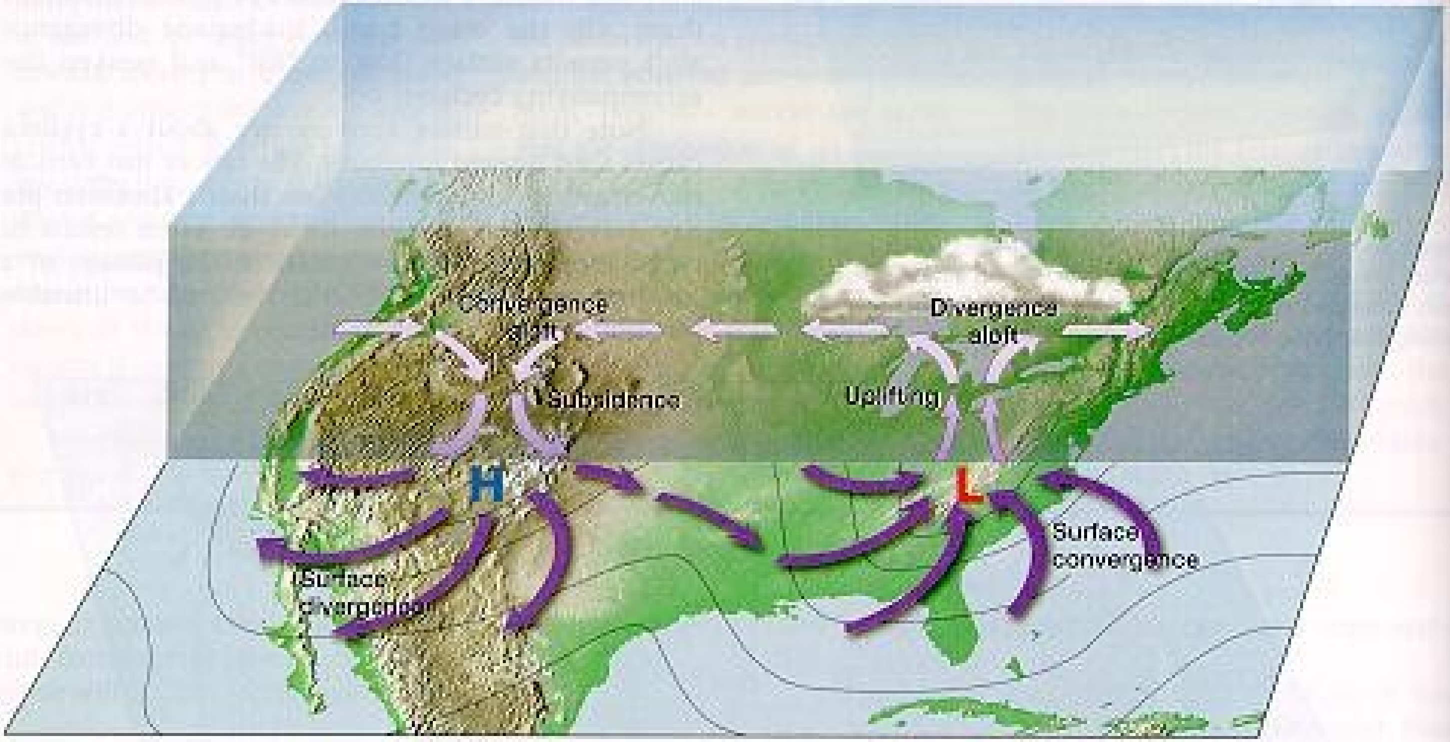


Figure 6–19 Airflow associated with surface cyclones and anticyclones. A low, or cyclone, has converging surface winds and rising air causing cloudy conditions. A high, or anticyclone, has diverging surface winds and descending air, which leads to clear skies and fair weather.